REMARKS

As a preliminary matter, Applicants appreciate the Examiner's indication that Claims 1-7 and 13-21 have been allowed.

Claim 22 stands rejected under 35 U.S.C. § 103 as being unpatentable over United States Patent No. 6,493,194 to Sakaguchi et al. Applicants respectfully traverse this rejection.

As noted by the Examiner in paragraph 3 on page 4 of the Final Office Action, Claim 22 would be allowed if Applicants were to submit a certified translation of the foreign priority document, which predates the U.S. filing date of the Sakaguchi et al. reference. Accordingly, enclosed herewith is a verified English translation of Japanese priority document number 2000-092227. The certified copy of this document was filed on December 27, 2000. The Sakaguchi et al reference has a United States filing date of March 30, 2000. The foreign priority reference of the present application has a filing date of March 29, 2000. Thus, the foreign priority date of the present invention is earlier than the United States filing dates of the Sakaguchi et al. reference. As the claim for foreign priority has been perfected with the filing of the enclosed verified translation, Applicants respectfully request that the §103 rejection of Claim 22 be withdrawn. See MPEP § 201.15.

For all of the above reasons, Applicants request reconsideration and allowance of the claimed invention. Should the Examiner be of the opinion that a telephone conference

would aid in the prosecution of the application, or that outstanding issues exist, the Examiner is invited to contact the undersigned.

Respectfully submitted,

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I, Tadahiko Itoh, a Patent Attorney of Tokyo, Japan having my office at 32nd Floor, Yebisu Garden Place Tower, 20-3 Ebisu 4-Chome, Shibuya-Ku, Tokyo 150-6032, Japan do solemnly and sincerely declare that I am the translator of the attached English language translation and certify that the attached English language translation is a correct, true and faithful translation of Japanese Patent Application No. 2000-092227 to the best of my knowledge and belief.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

MAY. 18. 2005

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PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this office.

Date of Application: March 29, 2000

Application Number: Japanese Patent Application No. 2000-092227

Applicant(s) FUJITSU LIMITED

October 20, 2000

Commissioner,
Patent Office Kouzo Oikawa (Seal)

Certificate No.2000-3086306

(Document Name)	Application For Patent
(Reference Number)	0040087
(Date of Submission)	March 29, 2000
(Destination)	Commissioner of Patent Office Mr. Takahiko Kondo
(IPC)	H01L 21/00
(Title of the Invention)	GIANT MAGNETO-RESISTIVE DEVICE AND A FABRICATION PROCESS THEREOF
(Number of Claims)	6
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(Indication of Official Fees)	
(Prepayment Ledger Number)	002989
(Amount Paid)	21000
(Other)	Patent Application based on contract research of the Japanese Government ("Promotion of Ultra-advanced Electron Technologies" 2001 New Energy and Industrial Technology Development Organization (Promotion of Ultra-advanced Electron Technologies), subject to Law on Special Measures for

Industrial Revitalization)

(Lists of Submitted Documents)

(Document Name)	Specification 1
(Document Name)	Drawing 1
(Document Name)	Abstract 1
(Number of General Power of Attorney)	9704678
(Proof Requested or Not)	Requested

[Name of Document] Specification

[Title of the Invention]

GIANT MAGNETO-RESISTIVE DEVICE AND A FABRICATION PROCESS THEREOF

[Claims]

1. A magneto-resistive magnetic sensor, comprising:

a magneto-resistive film changing a magnetic signal to an electric signal through transitions of magneto-resistance,

a cap film provided on a top surface of said magneto-resistive film to protect said magneto-resistive film, and

a conductive protective film provided on a top surface of said cap film to protect said cap film,

wherein both lateral ends of said magneto-resistive film are partly overlaid by a electrode layer.

2. A magneto-resistive magnetic sensor as claimed in claim 1, wherein said conductive protective film is formed of a metal selected from the group consisting of Au, Pt and Cu.

3. A magneto-resistive magnetic sensor as claimed in claim 2, wherein said conductive protective film is a Au conductive protective film whose thickness is between 10Å and 100Å.

4. A method of fabricating a magneto-resistive magnetic sensor, comprising the steps of:

forming a magneto-resistive film on a substrate;

depositing a cap film on said magneto-resistive film to protect said magneto-resistive film;

depositing a conductive protective film on said cap film to protect said cap film, said magneto-

resistive film, said cap film and said conductive protective film forming thereby a magneto-resistive layer;

patterning said magneto-resistive layer to a given dimension;

forming a pair of domain control regions at both lateral sides of said magneto-resistive layer;

depositing an electrode layer on said substrate such that said electrode layer covers said magneto-resistive layer and said domain control regions continuously;

patterning said electrode layer to form a pair of electrodes on said magneto-resistive layer, said step of patterning being conducted by applying an etching process to said electrode layer until said conductive protective film is exposed; and

patterning said conductive protective film until said cap layer is exposed.

5. A method as claimed in claim 4, wherein said step of depositing said conductive protective film comprises the step of depositing an Au layer as said conductive protective film, wherein said step of patterning said electrode layer comprises the step of a reactive-ion etching process, and wherein said step of patterning said conductive protective film comprises a ion milling process to remove unwanted parts of Au layer.

6. A method as claimed in claim 4, wherein said step of depositing said conductive protective film comprises the step of depositing an Au layer as said conductive protective film, and wherein said step of patterning said electrode layer and patterning said conductive protective film comprise an ion milling process to remove unwanted parts of Au layer.

[Detailed Description of the Invention]

[Field of the Invention]

The present invention generally relates to magnetic sensors and more particularly to a giant magneto-resistive device and a magnetic head using such a giant magneto-resistive sensor.

Magneto-resistive sensors are used extensively in magnetic heads of various conventional magnetic disk drives for reading information from a magnetic track formed on a magnetic disk.

[Prior Art]

A giant magneto-resistive sensor is a magnetic sensor having a superior magnetic sensitivity over an ordinary magneto-resistive sensor and is used in high-density magnetic disk drives. A typical example of a giant magneto-resistive sensor is a spin-valve sensor that can provide a magneto-resistive ratio exceeding 6%. A spin-valve sensor detects a magneto-resistance between a ferromagnetic free layer having a variable magnetization and a ferromagnetic pinned layer having a pinned magnetization, wherein the pinning of magnetization of the pinned layer is caused by an exchange coupling with an anti-ferromagnetic layer provided adjacent to the pinned layer, wherein the anti-ferromagnetic layer acts as a pinning layer to the pinned layer.

With ever-increasing trend of recording density in the technology of disk storage devices, the importance of giant magneto-resistive sensor has increased evermore.

In a high-density magnetic disk of future, a recording density of 40 Gbit/inch^2 is projected. In such a high-density magnetic recording device, the magnetic disk carries recording tracks with a pitch of 57 - 80 kTPI, which corresponds to a track separation of 0.45 - 0.32μm. In order to pickup magnetic signals

from such high-density tracks, it is necessary to narrow the width (read-core width) of the giant magneto-resistive sensor to be 0.25μm or less. In order to reduce the width of the giant magneto-resistive magnetic sensor, it is inevitable to apply a photolithographic process.

However, such a use of photolithographic process in the fabrication process of a giant magneto-resistive sensor raises a serious problem of oxidation of the anti-ferromagnetic layer used therein during the photolithographic process, which is conducted in the atmosphere. Further, the process of removing a resist mask may cause damage in the anti-ferromagnetic layer by the chemicals used for the removal of the resist mask.

Thus, it has been practiced in the art of giant magneto-resistive sensor of highly miniaturized width to protect the anti-ferromagnetic film in the photolithographic process by a metal cap film not reacting with the anti-ferromagnetic film, such as Ta.

FIG.1 shows the construction of a miniaturized spin-valve sensor 10 according to a related art.

Referring to FIG.1, the magnetic sensor 10 includes a magneto-resistive layer 13 for detecting a magnetic signal Hsig, wherein the magneto-resistive layer 13 has a standard layered structure of a spin-valve magnetic sensor and includes a ferromagnetic free layer, a ferromagnetic pinned layer, a conductive intermediate layer interposed between the free layer and the pinned layer, and an anti-ferromagnetic pinning layer provided on the pinned layer. For picking up magnetic signals Hsig from the magnetic tracks having an extremely miniaturized width, the magneto-resistive layer 13 also has a reduced width W. Such a miniaturized magneto-resistive layer 13 is obtained by conducting a photolithographic process as

noted before. Thereby, it should be noted that the top surface of the magneto-resistive layer 13 of the construction of FIG.1 is covered with a metal cap film such as Ta.

Further, the spin-valve sensor 10 of FIG.1 includes a pair of domain-control regions 12 of a hard magnetic material disposed at both lateral sides of the magneto-resistive layer 13, and electrode 11 is provided on the foregoing domain-control regions 12, respectively. The spin-valve sensor 10 of FIG.1 is called "abutted type sensor."

In the construction of FIG.1, it should be noted that the domain-control regions 12 have a predetermined magnetization 15 not responding to the external magnetic signal Hsig to the magneto-resistive layer 13 due to the large coercive force pertinent to a hard magnetic material, and the foregoing magnetization 15 of the domain-control regions 12 eliminates domain formation in the magneto-resistive layer 13, and hence, Barkhausen noise associated with the migration of the magnetic domain wall.

As a result, the magnetization 17 of the free layer in the magneto-resistive layer 13 changes the direction in response the external magnetic signal Hsig, and the magneto-resistance between the pinned layer and the free layer is changed accordingly. This change of the magneto-resistance is detected by causing to flow a sensing current 14 from one part of electrode 11 to another part of electrode 11 through the magneto-resistive layer 13 as represented in FIG.1.

In the construction of FIG.1, it will be noted that there is formed region 16 in the magneto-resistive layer 13, more precisely in the free layer of the magneto-resistive layer 13, in which the direction of magnetization does not change in response to the external magnetic field Hsig, along the boundary to the domain-control regions 12. It should

be noted that the magnetization 15 of the domain-control regions 12 causes a pinning of magnetization in the free layer in correspondence to the foregoing region 16. Thus, the foregoing region 16 forms a dead zone. In view of the fact that the sensing current 14 flows through such dead zone 16, the signal-to-noise ratio of the sensing current 14, and hence the sensitivity of the spin-valve magnetic sensor 10 of FIG.1, is inevitably deteriorated. This problem becomes particularly conspicuous when the magneto-resistive region 13 has a reduced width W.

In order to overcome the foregoing problem, there is a proposal of a spin-valve magnetic sensor 20 according to a related art as represented in FIG.2, wherein those parts corresponding to the parts explained with reference to FIG.1 are designated by the same reference numerals and the description thereof will be omitted.

[Problems to be Solved by the Invention]

Referring to FIG.2, the spin-valve magnetic sensor 20 has a construction similar to that of the spin-valve magnetic sensor 10 of FIG.1 except that the electrode 21 is formed so as to extend over the magneto-resistive layer 23 to form overhang regions 28 respectively.

More specifically, the overhang region 28 of the electrode 21 extends beyond the dead zone 26 on the top surface of the magneto-resistive layer 23. As noted previously, the top surface of the magneto-resistive layer 23 is covered by the metal cap film such as a Ta film.

According to the construction of FIG.2, the sensing current 24 is caused to flow while avoiding the dead zones 26, and the sensitivity of the magnetic sensor 20 is improved over the magnetic sensor 10 of FIG.1. The spin-valve sensor 20 of FIG.2 is called an

"overlay type sensor."

In the overlay type sensor 20 of FIG.2, it will be noted that the sensing current is injected into the magneto-resistive layer 23 across the interface between the electrode 21 and the magneto-resistive layer 23. Thus, the electric property of the metal cap film, typically a Ta film, provided on the top surface of the magneto-resistive layer 23 becomes important in the overlay type magnetic sensor 20 of FIG.2.

As noted previously, such a metal cap film is provided to protect the anti-ferromagnetic pinning layer in the magneto-resistive layer 23 during the photolithographic process. As a photolithographic process includes various processes conducted in the atmosphere such as resist process, there is a substantial risk that the surface of the metal cap film is oxidized. In the case of a Ta cap film, for example, there is a possibility that the surface of the Ta cap film is covered by an oxide film of Ta_2O_5.

It will be understood that the existence of such an oxide film on the surface of the metal cap film increases the resistance of the sensing current path, and the signal-to-noise ratio of the magnetic sensor is deteriorated. In addition, there is a possibility that the sensing current 24 avoids the oxide film and flows along the path of FIG.1. In this case, the sensing current 24 flows through the dead zone 26 and the signal-to-noise ratio of the magnetic sensor is deteriorated.

In addition, the abutting type sensor 20 of FIG.2 has another problem, in relation to the fabrication process thereof, in that the metal cap film of Ta may be etched during the etching process to form the electrode 21. Thus, when there is an excessive etching during the etching process for patterning the electrode 21, the anti-ferromagnetic

layer constituting a part of the magneto-resistive layer 23 may be damaged. In such a case, the exchange coupling magnetic field Hua caused by the anti-ferromagnetic layer would be influenced and the magneto-resistance of the magnetic sensor may be degraded seriously.

[Means to Solve the Problems]

Accordingly, it is a general object of the present invention to provide a novel and useful giant magneto-resistive sensor wherein the foregoing problems are eliminated.

Another and more specific object of the present invention is to provide a giant magneto-resistive sensor having a miniaturized size and simultaneously a high sensitivity for magnetic field detection.

Another object of the present invention is to provide a magneto-resistive sensor, comprising:

a magneto-resistive structure changing a resistance thereof in response to an external magnetic field, said magneto-resistive structure;

a cap layer provided on a top surface of said magneto-resistive structure;

a pair of magnetic regions disposed at both lateral sides of said magneto-resistive structure, said magnetic regions having a magnetization pointing in a common direction;

a pair of electrodes provided on said pair of magnetic regions so as to oppose with each other across said magneto-resistive structure, said electrodes having respective overhang parts extending over said magneto-resistive structure so as to oppose with each other with a gap therebetween,

wherein each of said overhang parts covers said cap layer on said magneto-resistive structure in such a state that an oxidation-resistant conductive

layer is interposed between said cap layer and said overhang part.

According to the present invention, the problem of increase of contact resistance at the interface between the cap layer and the electrode, caused as a result of oxidation of the cap layer surface during a patterning process of the magneto-resistive structure in the conventional overlay type giant magneto-resistive sensor, is effectively and positively eliminated by covering the cap layer by the oxidation-resistant conductive layer such as Au. As a result of decrease of the contact resistance, the magnetic sensor of the present invention can provide an improved signal-to-noise ratio, and hence an improved sensitivity. As a result of forming the overhang part in both electrodes, the current path of the sensing current successfully avoids the dead zone of the magneto-resistive structure, wherein the present invention can ensure that the sensing current path avoids the dead zone by reducing the contact resistance immediately underneath the overhang parts.

Other objects and further features of the present invention will become apparent from the following detailed description when read in conjunction with the attached drawings.

[Embodiments of the Invention]

Next, a spin-valve magnetic sensor 200 according to a preferred embodiment of the present invention will be described with reference to FIGS.3A - 5H showing a fabrication process of the spin-valve sensor 200.

Referring to FIG.3A, a spin-valve structure 100 is constructed on a Si substrate 101 covered with an SiO_2 film (not shown), wherein the spin-valve structure 100 includes a foundation layer 102 of Ta formed on the substrate 101 with a thickness of about

5nm. On the foundation layer 102, a ferromagnetic free layer 103 is formed by depositing a NiFe alloy layer and a CoFeB layer consecutively on the foundation layer 102 with respective thicknesses of 2nm and 1.5nm.

On the free layer 103, a non-magnetic separation layer 104 is formed by depositing a Cu layer with a thickness of about 2.8nm, and a Second pinned layer 105 of CoFeB is formed on the non-magnetic layer 104 with a thickness of about 2nm. Further, an exchange-coupling layer 106 of Ru and a first pinned layer 107 of CoFeB are deposited consecutively on the Second pinned layer 105 with respective thicknesses of 0.82nm and 1.5nm, and an anti-ferromagnetic pinning layer 108 of PdPtMn is deposited on the first pinned layer 107 with a thickness of about 13nm. The layers 103 - 108 form an ordinary spin-valve film MR.

The spin-valve film MR thus formed is further covered with a cap film 109 of Ta with a thickness of about 6nm, wherein the cap film 109 protects the anti-ferromagnetic layer 108 during the photolithographic patterning process of the spin-valve structure 100 so as to reduce the width W in conformity with the small track width on the high-density magnetic disk. The cap film 109 should not cause a reaction with the anti-ferromagnetic layer 108, and thus, it has been practiced to use Ta for this purpose.

In the present embodiment, it should be noted that the cap film 109 is further covered with a conductive protective film 110 of Au with a thickness of about 5nm. Thereby, the cap film 109 and the conductive protective film 110 are formed consecutively in a sputtering apparatus in continuation to the process of forming the spin-valve layer MR, without breaking the vacuum. Thus, there is no chance at all for the cap film 109 to be oxidized,

and an excellent contact is achieved at the interface between the anti-ferromagnetic film 108 and the Ta cap film 109 and further at the interface between the Ta cap film 109 and the Au conductive protective film 110.

Next, in the step of FIG.3B, a resist pattern 130 having a thickness of 1.0μm is provided on the Au film 110 according to the desired size and shape of spin-valve structure 100 to be formed as in the case of the magneto-resistive layer 13 of FIG.2, and an ion milling process using Ar ions 140 is applied so as to pattern the layers 102 - 110 of the spin-valve structure 100 of FIG.3A while using the resist pattern 130 as a mask. In FIG.3B, it should be noted that the layers 102 - 108 are collectively designated as the spin-valve layer MR, as noted previously. As a result of the ion milling patterning process, which acts substantially perpendicularly to the substrate 101, the spin-valve layer MR and the layers 109 and 110 thereon, in other words the spin-valve structure 100 of FIG.3A, are patterned in accordance with the resist pattern 130.

Next, in the step of FIG.3C, a ferromagnetic layer of CoCrPt is deposited at both lateral sizes of the patterned spin-valve structure 100 by a sputtering process while using the resist pattern 130 as a mask, and domain control region 115 of CoCrPt are formed in correspondence to the domain control regions 12 of FIG.2. It should be noted that FIG.3C shows the state in which the resist pattern 130 is removed by an ashing process after the formation of the domain control region 115.

Next, in the step of FIG.3D, a Ta film (not shown) is deposited on the structure of FIG.3C uniformly with a thickness of about 7nm including the top surface of the domain control region 115 and the top surface of the Au protective layer 110, and an electrode layer 117 of Mo is deposited further thereon

by a sputtering process with a thickness of about 50nm.

Further, a step of FIG.4E is conducted in which a resist pattern 135 having a thickness of about 1μm is formed on the structure of FIG.3D, and the resist pattern 135 is formed to have a resist opening so as to expose a part of the electrode layer 117 to be removed, wherein the foregoing exposed part of the electrode layer 117 corresponds to a central part of the structure patterned in the step of FIG.3B.

During the resist process of FIG.4E, it is again noted that there is no chance at all for the Ta cap film 109 to contact with the air, as the Ta cap film 109 is covered entirely by the Au protective film 110. Thus, formation of undesirable oxide on the top surface of the Ta cap film 109 is positively and inherently prevented.

Next, in the step of FIG.4F, a reactive ion etching process using SF_6 142 as an etching gas is applied to the electrode layer 117 through the resist opening until the Au protective film 110 is exposed, and electrodes 117A and 117B are formed from the electrode layer 117 such that the electrodes 117A and 117B oppose with each other on the top surface of the Au protective film 110. As noted previously, the Au protective film 110 covers the Ta cap film 109 on the top surface of the spin-valve layer MR.

It should be noted that the reactive ion etching process of FIG.4F reacts selectively upon the Au protective film 110 and stops spontaneously upon exposure of the Ta cap film 109. Further, it should be noted that an attempt to extend the duration of the etching process in the step of FIG.4F by 20% over the nominal etching time to expose the top surface of the protective film 110 has revealed the fact that no exposure of the underlying Ta cap film 109 is caused, indicating that a sufficient margin is secured for the reactive ion etching process during the process of

patterning the electrodes 117A and 117B.

The electrodes 117A and 117B thus formed have respective overhang parts extending toward each other over the top surface of the Au protective film 110 similarly to the overlay-type magnetic sensor 20 of FIG.2.

Next, in the step of FIG.4G, an ion milling process is applied to the structure of FIG.4F while using Ar ions impinging in the direction generally perpendicularly to the substrate 101 for several seconds, and the exposed part of the Au protective film 110 is removed. As a result of removal of the low-resistance Au protective film from the region between the electrodes 117A and 117B, the shunt current path of the sensing current is eliminated.

By using an ion milling process, which acts selectively upon an Au film in the step of FIG.4G, the ion milling process stops substantially spontaneously upon the exposure of the Ta film 109, and the risk that the top surface of the spin-valve layer MR being exposed is effectively avoided.

After removal of the resist pattern 135 by a plasma ashing process or a chemical process, the spin-valve magnetic sensor 200 as represented in FIG.5H is obtained.

Thus, the top surface of the Ta cap film 109 contacting with the electrode 117A or 117B and serving for a part of the current path of the sensing current is protected by the Au protective film 110 throughout the process. Thus, there is no chance at all that an oxide film is formed on the top surface of the Ta cap film 109 and a low resistance is guaranteed for the sensing current path. Thereby, it should be noted that the Au protective film 110 has an inherently low resistance, and the spin-valve magnetic sensor 200 of the present embodiment provides an excellent performance for feeble magnetic detection. Further,

the spin-valve magnetic sensor 200 can be formed to have an extremely reduced width as a result of application of a photolithographic patterning process.

Next, the spin-valve magnetic sensor 200 is evaluated by using a four-terminal TEG (test element group) pattern represented in FIG.6.

FIG.7 shows the result of the evaluation.

More specifically, FIG.7 represents the relationship between the MR (magneto-resistive) ratio and the strength of the external magnetic field H.

As can be seen from FIG.7, the spin-valve magnetic sensor 200 of the present embodiment can achieve the MR ratio of as much as 5% in response to the change of the external magnetic field H from -400 Oe (-3.2×10^4A/m) to +400 Oe ($+3.2 \times 10^4$A/m). When there is formed an oxide layer on the surface of the Ta cap film 109 as in the case of the overlay type sensor of FIG.2, on the other hand, the MR ratio cannot exceed 4% as represented in FIG.7 by a broken line.

FIG.8 shows the result of the experiments conducted for evaluating the state of the protective film 110 formed on the Ta cap film 109 in the spin-valve sensor 200 of the present embodiment.

In the experiment, a Si substrate covered with an SiO2 film was prepared for a test body and a Ta film and an Au film were deposited on the substrate consecutively with respective thicknesses of 10nm and 70nm.

The test body thus formed was then subjected to a reactive ion etching process while using a fluoric etching gas (SF_6) in evaluation for the etching rate of the Au film. The etching was conducted under a pressure of 0.2Pa and 0.5Pa while using a plasma power of 100W and a bias power of 10W.

FIG.8 shows the etching rate thus observed, wherein the solid squares represent the result for the

case the process pressure was set to 0.5Pa, while the solid triangles represent the result for the case the process pressure was set to 0.2Pa.

Referring to FIG.8, it can be seen that the etching rate of the Au film is extremely low, in the order of only 0.08Å/s, wherein the relationship of FIG.8 was obtained by an X-ray fluorescent analysis.

The relationship of FIG.8 indicates that an Au film provides a very small etching rate, and thus, the Au protective film 110 of the spin-valve magnetic sensor 200 functions as an effective etching stopper when patterning the electrodes 117A and 117B in the step of FIG.4F. Naturally, the Ta cap film 109 underneath the Au protective film 110 is protected from the reactive ion etching process. Thereby, the etching process of FIG.4F can be conducted easily, without risking the underlying Ta film 109 to be damaged.

FIGS.9A and 9B show the result of experiments conducted on the effect of the Au protective film 110 on the magnetic property of the spin-valve structure 100 of FIG.3A.

Thus, a test body was formed by depositing a Ta foundation film on a Si substrate covered with an SiO_2 film, with a thickness of 5nm, and a ferromagnetic free layer, a non-magnetic separation layer, a first pinned layer, an intermediate coupling layer, a second pinned layer, and an anti-ferromagnetic pinning layer were formed consecutively on the Ta foundation layer. In the experiments, a stacking structure of a NeFe alloy layer and a CoFeB layer was used for the ferromagnetic layer with respective thicknesses of 2nm and 1.5nm. Further, a Cu layer having a thickness of 2.8nm was used for the non-magnetic separation layer, a CoFeB layer having a thickness of 2nm was used for the first pinned layer, a Ru layer having a thickness of 0.8nm was used for

the intermediate coupling layer, a CoFeB layer having a thickness of 1.5nm was used for the second pining layer, and a PdPtMn layer having a thickness of 13nm was used for the anti-ferromagnetic pinning layer.

The spin-valve structure thus formed was further covered with a cap film of Ta having a thickness of 6nm (60Å) and a conductive protective film of Au consecutively, wherein the thickness of the conductive protective film was changed variously.

More specifically, specimens having the Au film with the thicknesses of 1nm (10Å), 3nm (30Å), 5nm (50Å), 7nm (70Å) and 10 nm (100Å) were prepared and each of the specimens were subjected to the reactive ion etching process conducted under the pressure of 0.5Pa and the substrate temperature of 20°C while using the SF_6 etching gas, the plasma power of 100W, the bias power of 10W, and the d.c. bias voltage Vdc of 10V, for various durations.

FIG.9A shows the relationship between the observed pinning magnetic field Hua of the anti-ferromagnetic layer and the etching time, wherein open circles represent the case in which no Au protective film is provided, solid circles represent the case in which the Au protective film is provided with a thickness of 1nm, open squares represent the case in which the Au protective film is provided with a thickness of 3nm, open triangles represent the case in which the Au protective film is provided with a thickness of 5nm, solid triangles represent the case in which the Au protective film is provided with a thickness of 7nm, and solid squares represent the case in which the Au protective film is provided with a thickness of 10nm.

Referring to FIG.9A, it can be seen that the pinning magnetic field Hua drops sharply after 100 seconds when there is no Au protective film provided on the Ta cap film, indicating the existing of damages

in the anti-ferromagnetic layer as a result of the reactive ion etching process. This decrease of the pinning magnetic field Hua is improved when the Au protective film is provided with the thickness of 1nm or more, and the degree of improvement clearly increases with the thickness of the Au protective film exceeding about 3nm. When the thickness of the Au protective film has reached 10 nm, no substantial decrease is observed for the pinning magnetic field Hua.

FIG.9B shows the MR ratio of the spin-valve magnetic sensor 200 formed according to the process of FIGS.3A - 5H while using the spin-valve structure thus formed for various thicknesses of the Au protective layer. Similarly as before, the thickness of the Ta cap layer was set to 6nm throughout. Similarly to FIG.9A, open circles represent the case in which no Au protective film is provided, solid circles represent the case in which the Au protective film is provided with a thickness of 1nm, open squares represent the case in which the Au protective film is provided with a thickness of 3nm, open triangles represent the case in which the Au protective film is provided with a thickness of 5nm, solid triangles represent the case in which the Au protective film is provided with a thickness of 7nm, and solid squares represent the case in which the Au protective film is provided with a thickness of 10nm.

Referring to FIG.9B, it can be seen that the MR ratio drops sharply after 100 seconds when there is no Au protective film provided on the Ta cap film, while it is noted that the MR ratio of 6 - 8 is maintained for the duration of 100 seconds when the Au protective film is provided with the thickness of 1nm. Further, the duration of the high MR ratio increases when the Au protective film has exceeded the thickness of about 3nm.

The relationship of FIG.9B further indicates the tendency of increase of the MR ratio with the etching time before it starts the sharp dropping. It is believed that this tendency is caused as a result of the thinning of the Au protective film on the Ta cap film with the progress of the etching and associated interruption of the shunting current flowing through the Au protective film from the electrodes 117A to the electrode 117B, or vice versa.

From the experiments of FIG.9A and 9B, it is concludes that the Au protective film 110 of the spin-valve magnetic sensor 200 is preferably formed with the thickness of 3nm or more.

In the process of FIGS.4F and 4G, it should be noted that these process may be conducted in a single ion milling process. In this case, the fabrication process is simplified.

Further, it will be understood that the feature of the present invention of providing a Ta cap film 109 and the Au protective film 110 on a magneto-resistive structure is by no means limited to a spin-valve magnetic sensor but is applicable similarly to an ordinary magneto-resistive sensor that uses a single ferromagnetic layer such as FeNi alloy. Further, the present invention is applicable also to a spin-valve magnetic sensor in which the order of stacking of the layers is reversed. In this case, the Ta cap film 109 and the Au protective film 110 protect the ferromagnetic free layer 103, which is now provided at the top part of the spin-valve structure 100.

It should be noted that any oxidation-resistant low-resistance metal be used for the foregoing protective film 110. Thus, the protective film 110 may be formed of a metal selected from the group consisting of Au, Pt and Cu.

Further, the present invention is not limited to the embodiments described heretofore, but

various variations and modifications may be made without departing from the scope of the invention.

[Advantages of the Invention]

According to the invention described in claim 1, it is obvious from the aforementioned description that the cap film protects the magneto-resistive film and the conductive protective film protects the cap film. Therefore, the problems caused by the oxidization of the cap film in the conventional manufacturing process are solved, and a high sensitive, micro-fabricated magneto-resistive magnetic sensor becomes available.

[Brief Description of the Drawings]

FIG.1 is a diagram showing the construction of the conventional magneto-resistive magnetic sensor;

FIG.2 is a diagram showing the construction of the conventional overlaid-structured magneto-resistive magnetic sensor;

FIGS.3(A) - (D) are diagrams (Series 1) showing the fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention;

FIGS.4(E) - (G) are diagrams (Series 2) showing the fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention;

FIG.5(H) is a diagram (Series 3) showing the final fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention;

FIG.6 is a diagram showing the four-terminal TEG pattern used for evaluating the magneto-resistive magnetic sensor of the present embodiment;

FIG.7 is a diagram showing the operational characteristics based on TEG pattern evaluation in

FIG.6;

FIG.8 is a diagram showing the relationship between the etching amount and the etching time of an Au film; and

FIG.9(A) is a diagram showing the relationship between the etching time of Au film and the exchange coupling magnetic field Hua caused by the anti-ferromagnetic layer for various thicknesses of the Au film.

FIG.9(B) is a diagram showing the relationship between the etching time of Au film and the MR ratio for various thicknesses of the Au film.

[Description of the Reference Numbers]

100 Spin-valve structure
101 Substrate
102 Foundation layer
103 Ferromagnetic free layer
104 Non-magnetic separation layer
105 Second pinned layer
106 Exchange-coupling layer
107 First pinned layer
108 Anti-ferromagnetic pinning layer
109 Cap film
110 Conductive protective film
115 Domain control regions
117 Electrode layer
142 Reactive ion etching process
144 Ion milling process

[Name of Document] Drawings

FIG. 1 The construction of the conventional magneto-resistive magnetic sensor.

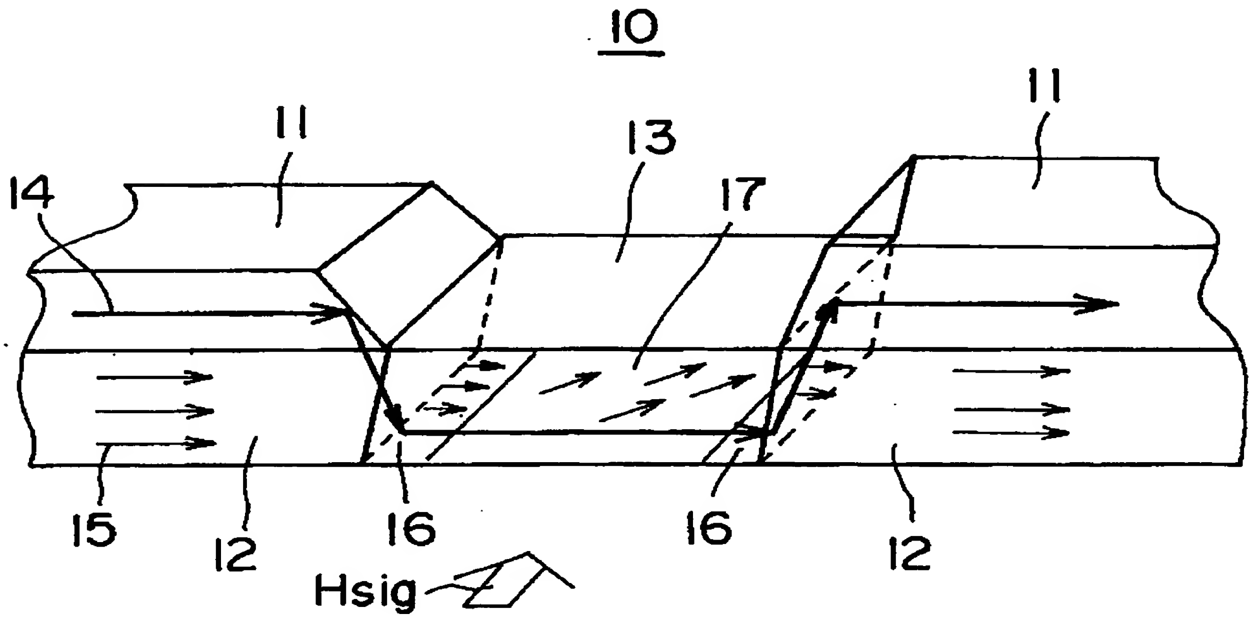


FIG. 2

The construction of the conventional overlaid-structured magneto-resistive magnetic sensor.

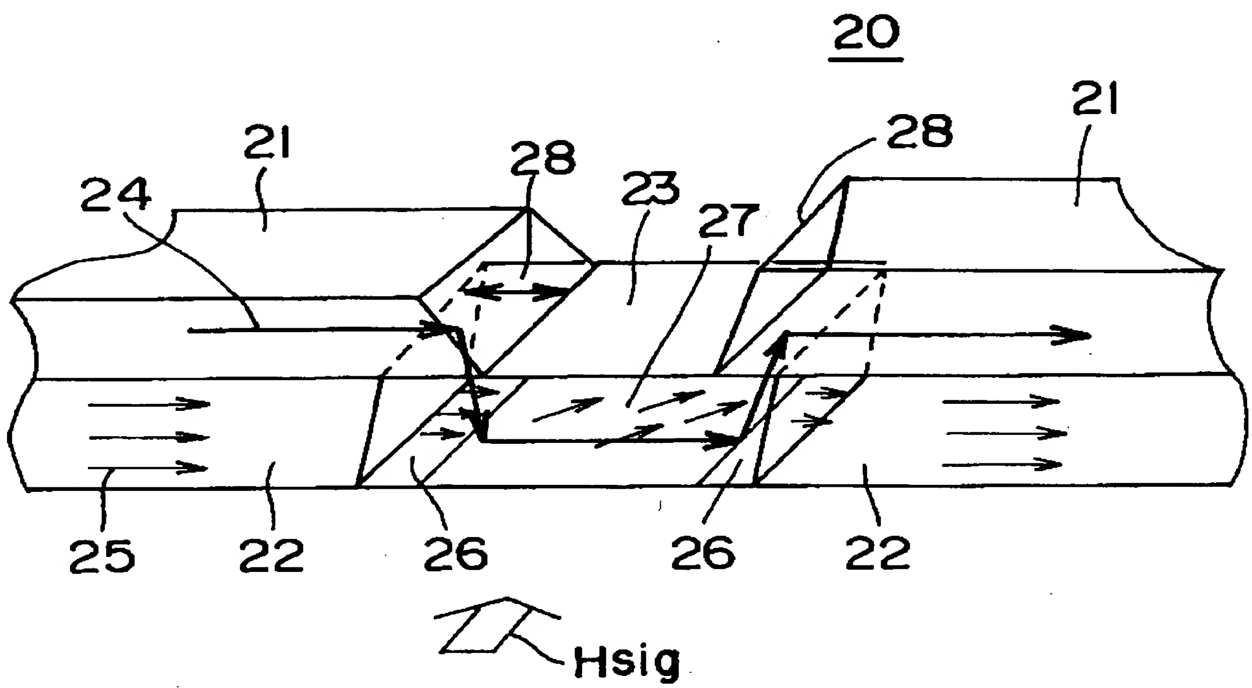


FIG. 3 The fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention (Series 1).

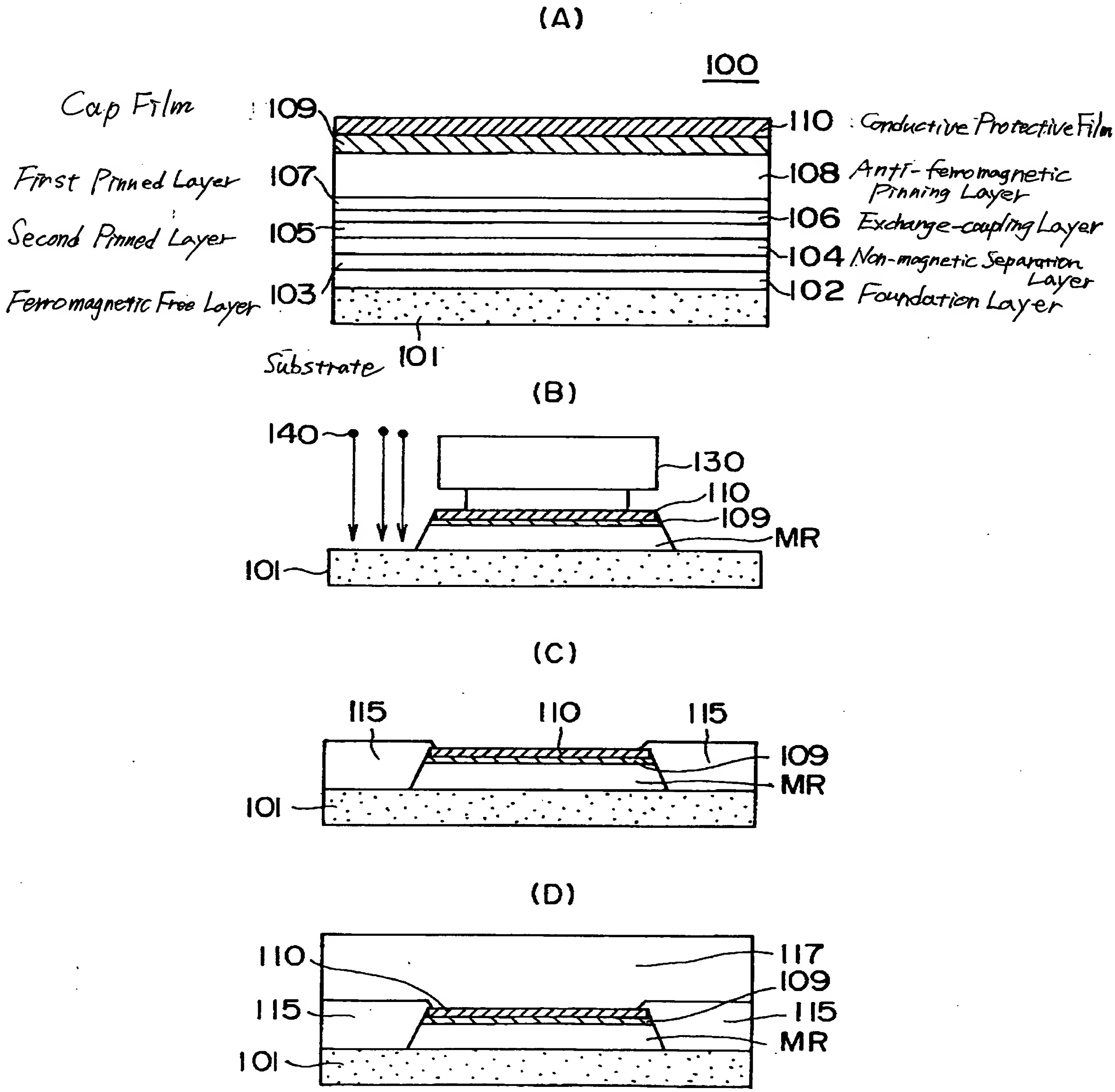
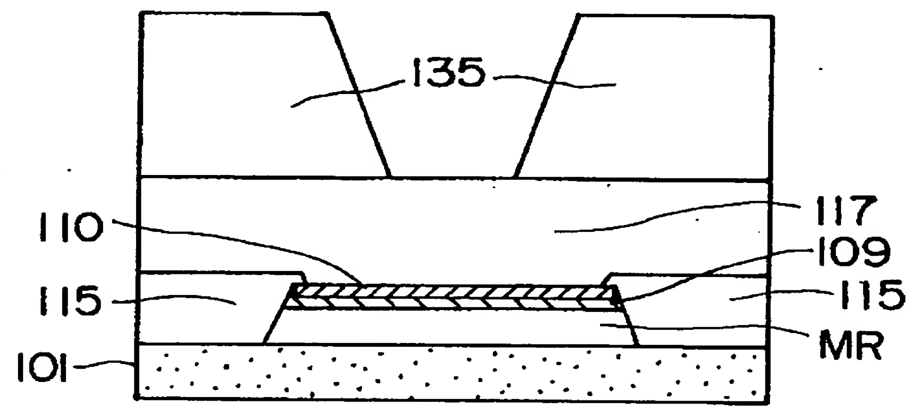
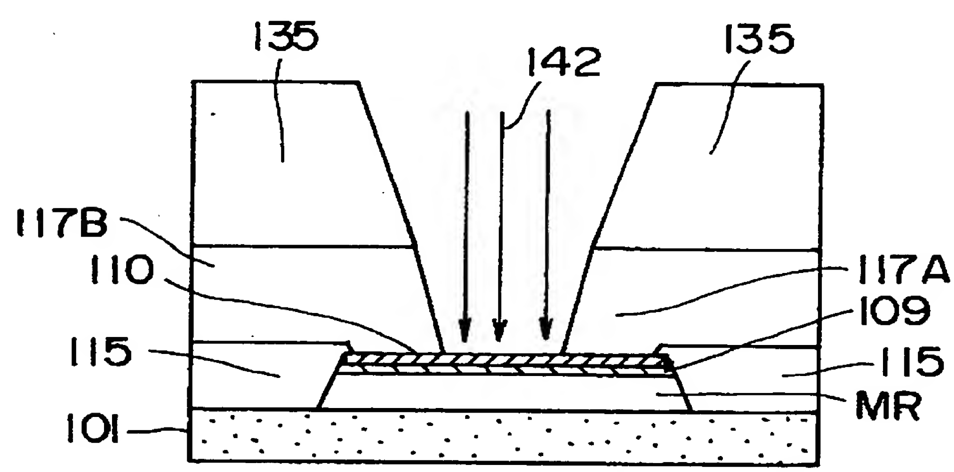


FIG. 4 The fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention (Series. 2).

(E)



(F)



(G)

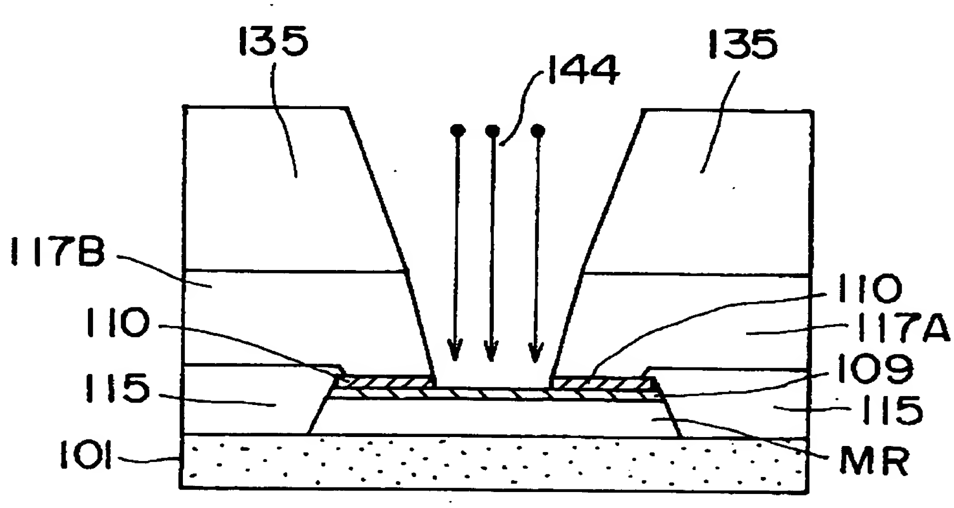


FIG. 5 The final fabrication process of the magneto-resistive magnetic sensor according to the embodiment of the present invention (Series 3);

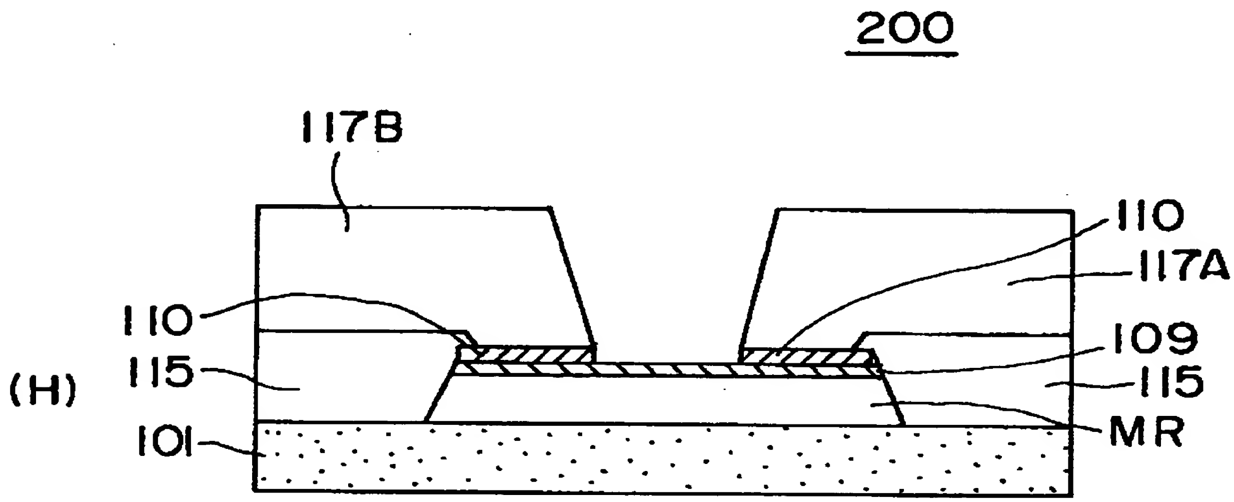


FIG. 6 The four-terminal TEG pattern used for evaluating the magneto-resistive magnetic sensor of the present embodiment.

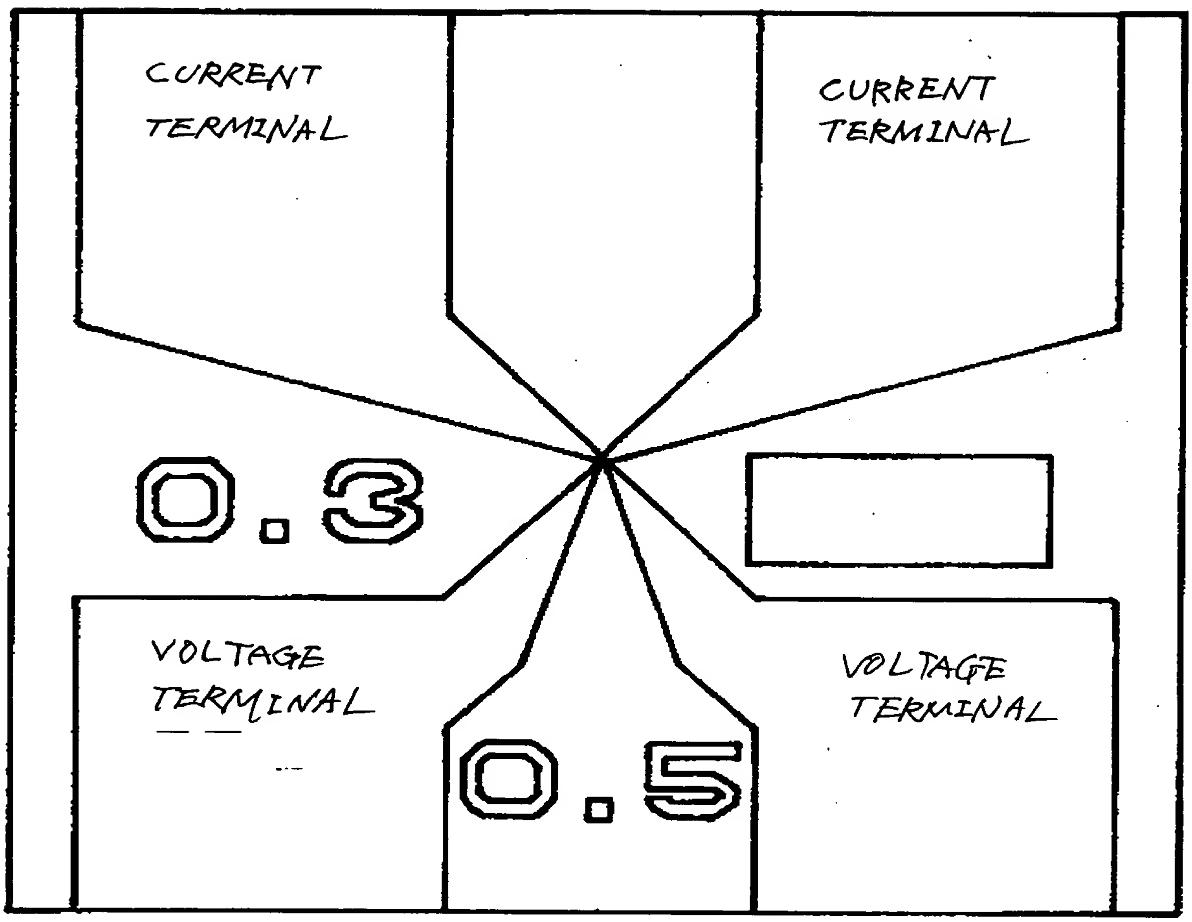


FIG. 7 The operational characteristics based on TEG pattern evaluation in FIG. 6.

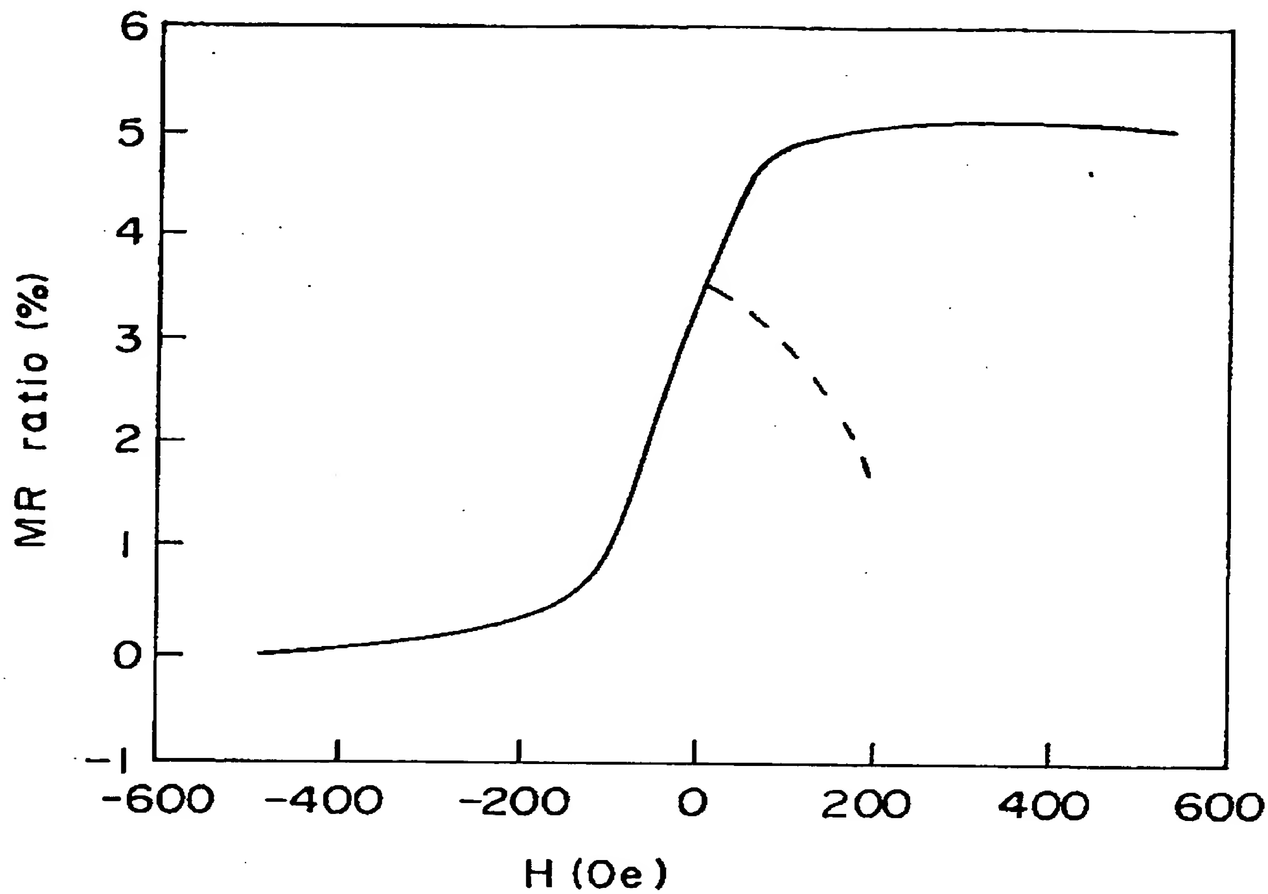


FIG.8 Relationship between the etching amount and the etching time of an Au film.

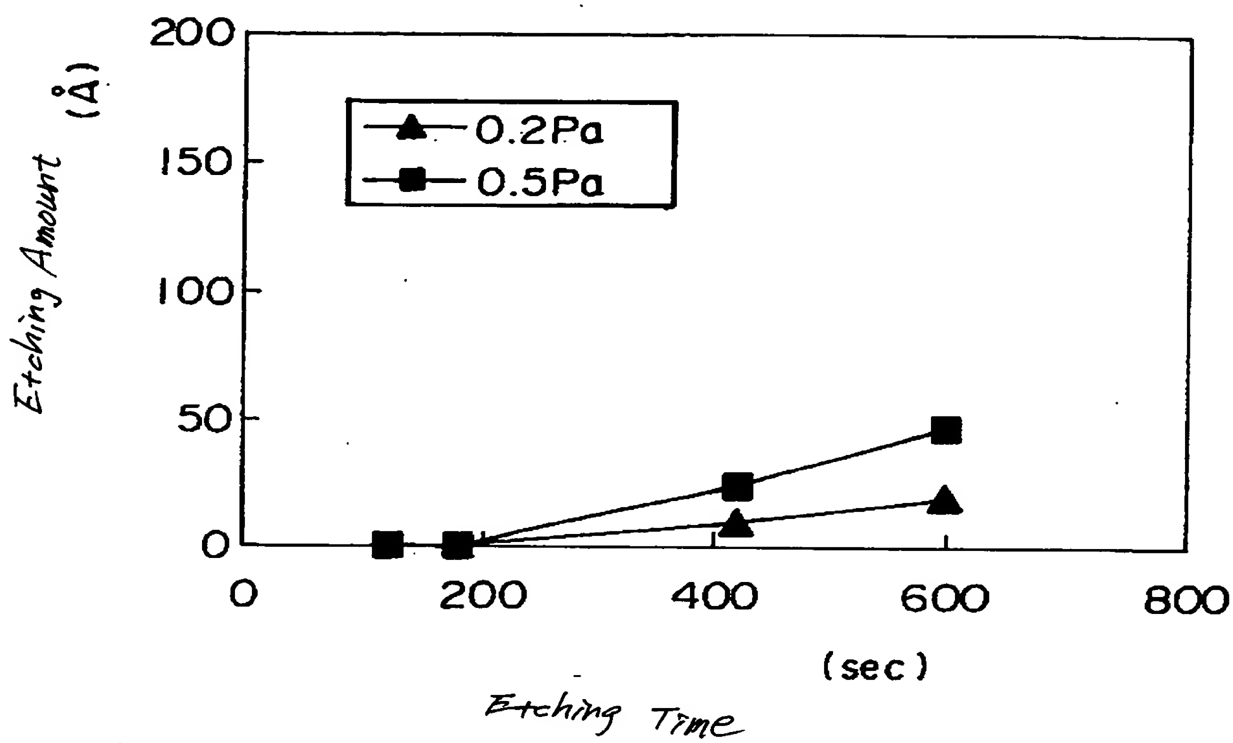


FIG. 9

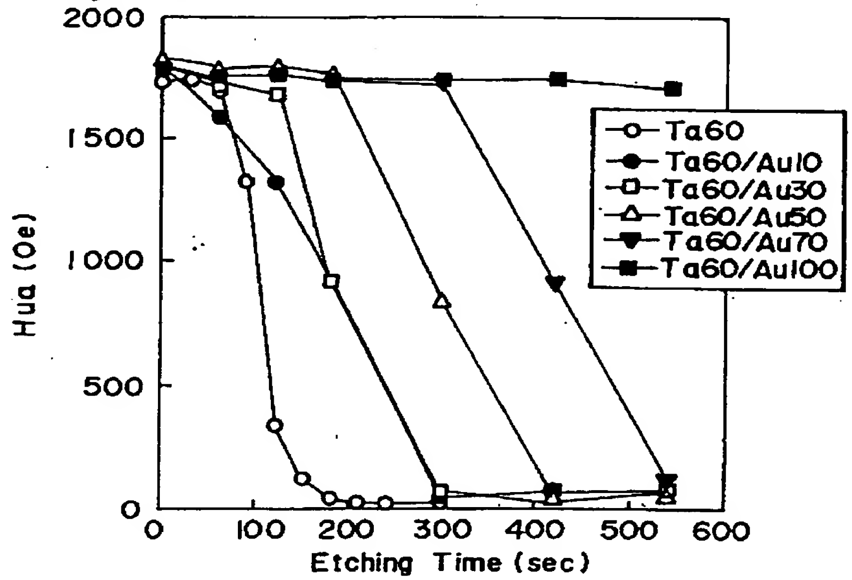
(A) Relationship between the etching time of Au film and the Exchage-coupling magnetic field Hua caused by the anti-ferromagnetic layer for various thickness of the Au film.

(B) Relationship between the etching time of Au film and the MR ratio for various thickness of the Au film.

The transition of Hua by the etching time of Au film on Spin-Valve film.

(Process Pressur: 0.5Pa, Plasma Power: 100W, Bias Power: 10W, Vdc: -10V, Substrate Temperature: 20℃)

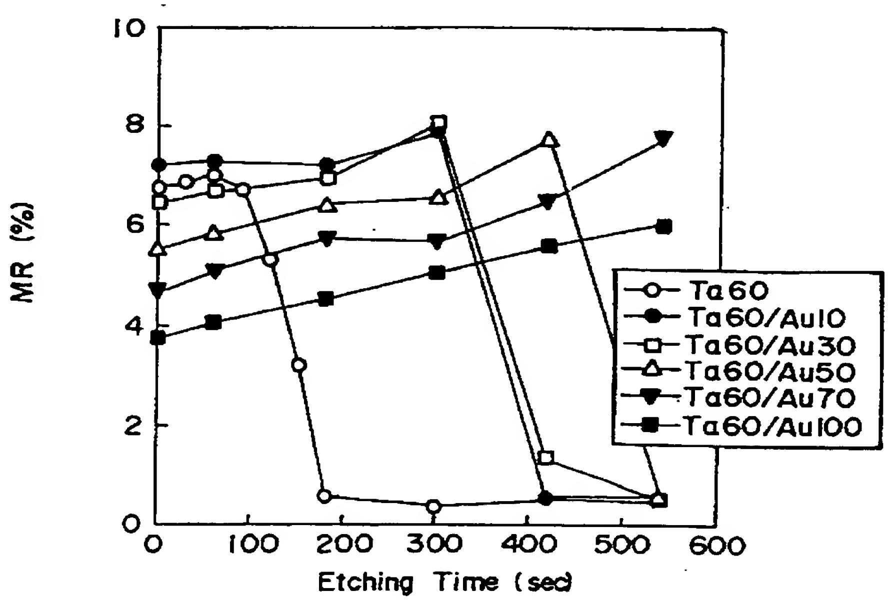
(A)



The transition of MR ratio by the etching time of Au film on Spin-Valve film.

(Process Pressure: 0.5Pa, Plasma Power: 100W, Bias Power: 10W, Vdc: 10V, Substrate Temperature: 20℃)

(B)



[Name of the Document] Abstract

[Abstract]

[Object]The object of the present invention is providing an overlaid-structured magneto-resistive magnetic sensor which achieves high sensitivity by avoiding the increase of resistance between electrodes caused by the corrosion of cap film which protects magneto-resistive film.

[Solution Means] A magneto-resistive magnetic sensor comprising a magneto-resistive film changing a magnetic signal to an electric signal through changes of magneto-resistance, a cap film provided on a top surface of said magneto-resistive film to protect said magneto-resistive film, and a conductive protective film provided on a top surface of said cap film to protect said cap film, wherein both lateral ends of said magneto-resistive film are partly overlaid by a electrode layer.

[Selected Figure] Fig.3